Fast-Charge and Low-Cost Lithium Ion Batteries for Electric Vehicles

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Project ID: BAT247

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Program Overview

TIMELINE

- Project start date: Feb 2019
- Project end date: Jul 2021
- Percent complete: 90%

BARRIERS

- Enable fast charge ($\leq$ 15 min) performance from high-energy lithium-ion batteries (LIBs)
- Meet cell cost target of 75 $/kWh
- Meet cycle life and calendar life from LIBs integrating silicon dominant anodes

BUDGET

- Total project funding:
  - ✓ DOE share: $2,421,022
  - ✓ Zenlabs share: $2,421,023
- Funding received in FY2020: $935,994
- Funding for FY2021: $622,869

PARTNERS

USABC UNITED STATES ADVANCED BATTERY CONSORTIUM

INL Idaho National Laboratory

Sandia National Laboratories

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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Relevance & Objectives

- **Goals:** To develop novel electrolyte formulations, a scalable pre-lithiation solution that enables the use of high-capacity silicon oxide anodes, and optimized cell designs that will result in lithium-ion batteries (LIBs) capable of meeting the USABC Low-Cost and Fast-Charge (LC/FC) electric vehicle (EV) battery goals for CY 2023

- **Objectives and Tasks:**
  - ✓ Develop electrolyte formulations able to passivate the silicon anode and NCM cathode, reduce gassing, support fast charging and improve calendar life
  - ✓ Support development of a low-cost manufacturable pre-Lithiation solution able to support silicon-based LIBs
  - ✓ Establish an optimized cell design to ensure meeting the USABC cell metrics, safety and cost targets
  - ✓ Develop and prototype large-capacity (10 - 60 Ah) pouch cells meeting the program cell specifications

- **Deliverables:**

  Demonstrate & deliver cells that meet the USABC LC/FC EV cell targets with independent validation from the National Labs (INL, SNL, & NREL)

- **USABC LC/FC EV Cell Targets for 2023:**

End of Life Characteristics at 30°C	Units	Cell Level
Peak Discharge Power Density, 30 s Pulse	W/L	1400
Peak Specific Discharge Power, 30 s Pulse	W/kg	700
Peak Specific Regen Power, 10 s Pulse	W/kg	300
Available Energy Density @ C/3 Discharge Rate	Wh/L	550
Available Specific Energy @ C/3 Discharge Rate	Wh/kg	275
Available Energy @ C/3 Discharge Rate	kWh	50
Calendar Life	Years	10
DST Discharge Throughput, Discharge Energy	MWh	50
Cost	$/kWh	75
Operating Environment	°C	-30 to +52
Normal Recharge Time	Hours	< 7 Hours, J1772
Fast High Rate Charge	Minutes	80% ΔSOC in 15 min
Minimum Operating Voltage	V	>0.55 Vmax
Unassisted Operating at Low Temperature	%	> 70% Useable Energy @ C/3 Discharge rate at -20 °C
Survival Temperature Range, 24 Hr	°C	-40 to+ 66
Maximum Self-discharge	%/month	< 1

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Milestones and Gates

Program Start *(Feb 1st, 2019)*
Current Status
End *(Jul 31st, 2021)*
2019 — 2020 — 2021

Task Number	Major Project Tasks	PROJECT TIME												
		YEAR 1				YEAR 2				YEAR 3				
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	
5	**MAJOR PROJECT DELIVERABLE SUMMARY**													
4.4	Ship 11 Ah capacity CB#1 pouch cells to the National Labs		◆											Complete
4.9	Ship 11 Ah capacity CB#2 pouch cells to the National Labs						◆							Complete
4.14	Ship 11 Ah & >40 Ah capacity CB#3 pouch cells to the National Labs										◆			ongoing
5.1	Deliver final USABC project report										◆			ongoing
9	**REVIEW AND DECISION GATES**													
1.3	Down-select best Pre-Li solution for Cell Build #2						◆							Complete
1.4	Down-select best Pre-Li solution for Cell Build #3										◆			ongoing
2.6	Down-select best electrolyte formulation for Cell Build #2						◆							Complete
2.7	Down-select best electrolyte formulation for Cell Build #3										◆			ongoing
3.10	Down-select best cell design for Cell Build #2						◆							Complete
3.11	Down-select best cell design for Cell Build #3										◆			ongoing
4.5	Freeze anode, cathode, electrolyte, and cell design for Cell Build #2						◆							Complete
4.10	Freeze anode, cathode, electrolyte, and cell design for Final Cell Build #3										◆			ongoing

- Milestones and gates associated with delivery of cell build #2 (task 1.3, 2.6, 3.10, 4.5, 4.9) are completed
- Ongoing development focuses on final program cell build #3 (task 1.4, 2.7, 3.11, 4.10, 4.14) to meet USABC LC/FC EV cell targets

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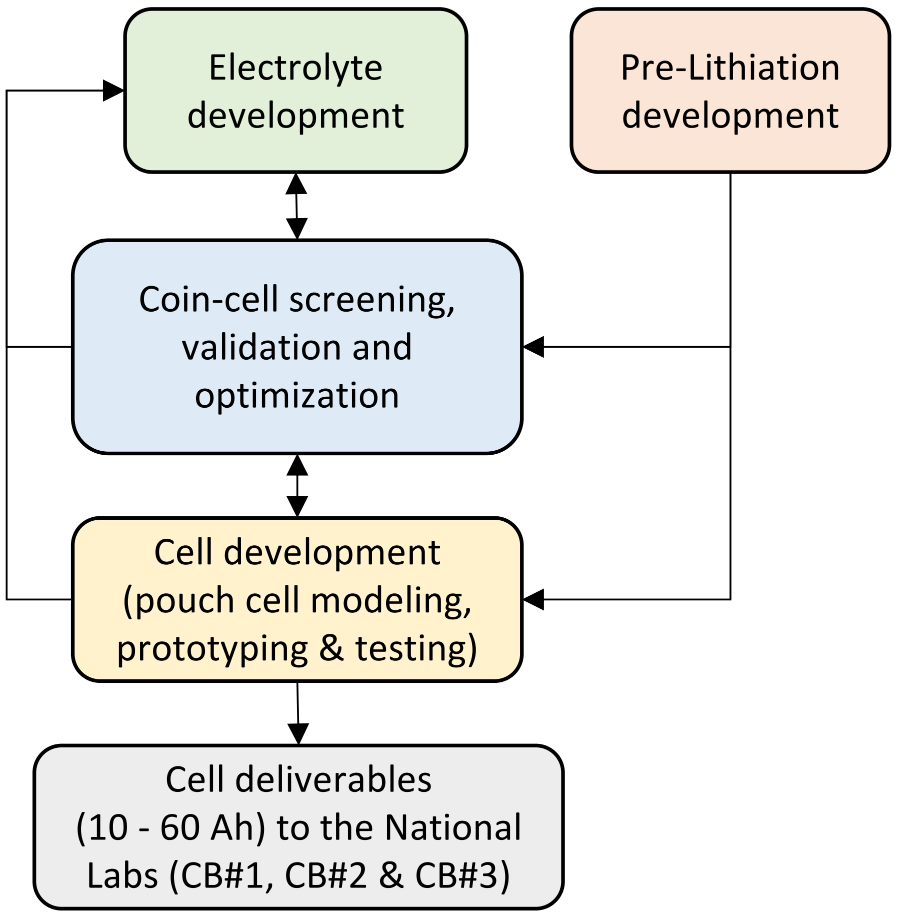
Approach

Material, process and cell development strategy:



- Zenlabs is optimizing different electrolyte formulations that incorporate commercially available organic carbonate solvents, additives and salts to meet the Low-Cost Fast-Charge USABC EV cell targets
- Developing and optimizing high throughput screening in coin-cells and pouch cells for cycle life, gas generation and calendar life
- Supporting and evaluating different Pre-lithiation solutions for silicon-based anodes that will address cost and manufacturability
- Iterative process to down-select the best active and passive components, cell design and cell processing necessary to meet the program targets

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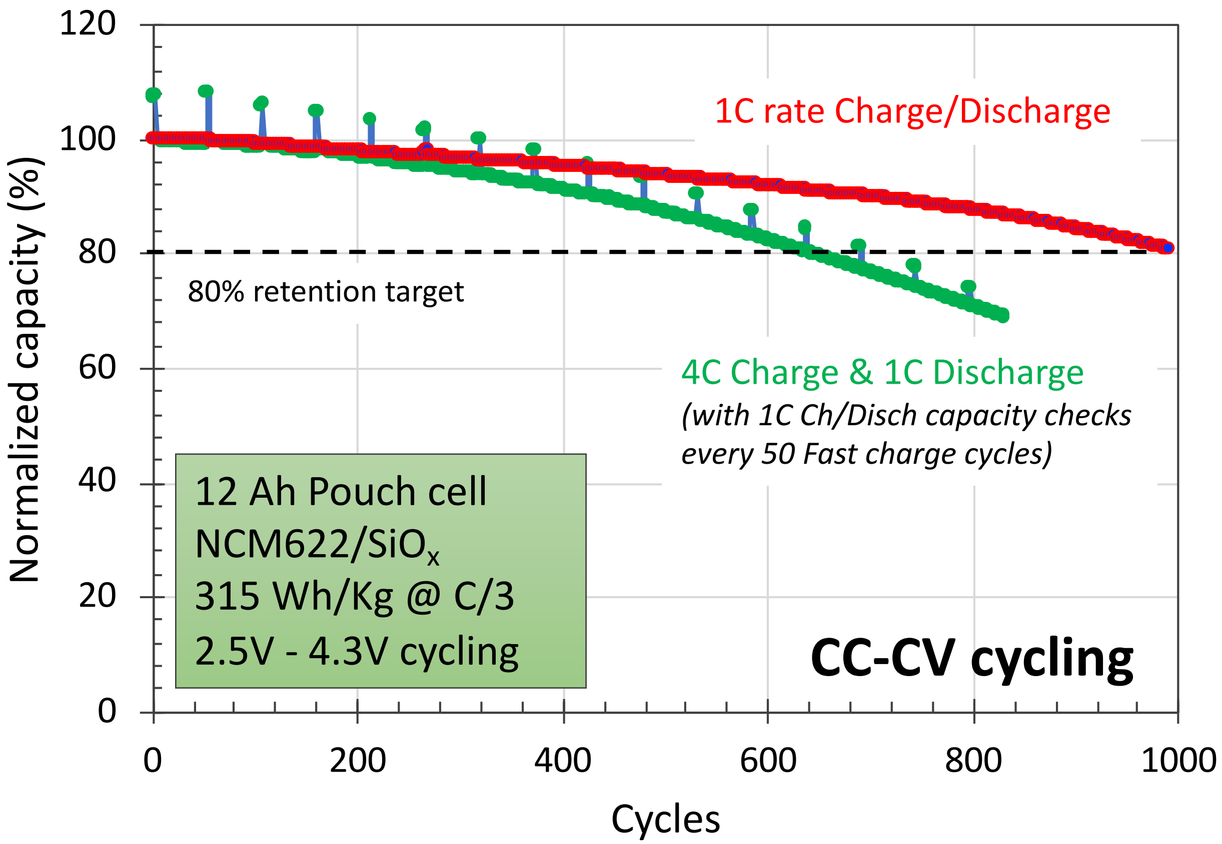
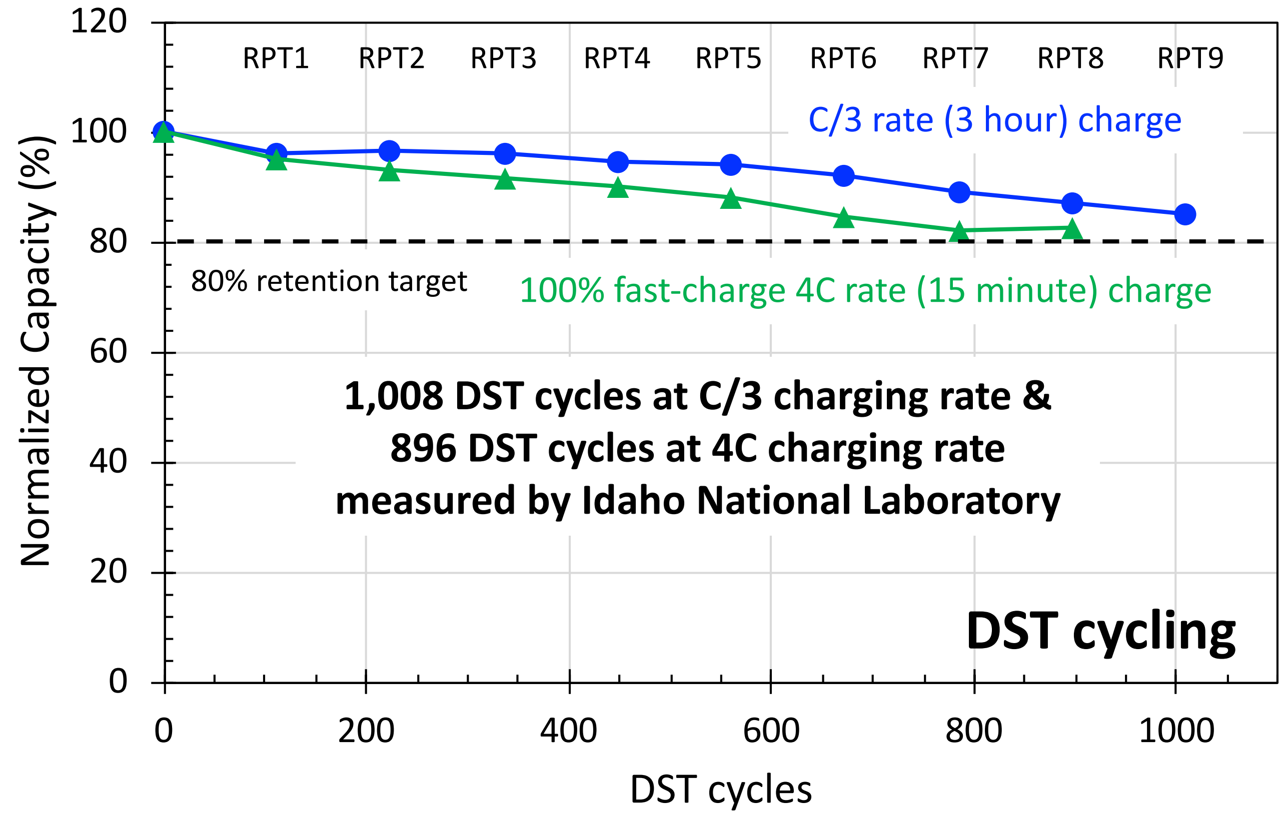
Accomplishments: 1000 Cycles Achieved





- **Have achieved >1000 cycles** to 80% capacity retention from 12 Ah, 315 Wh/kg pouch cells (rated at C/3) at 1C rate CC-CV cycling and C/3 charge rate DST cycling.
- Have achieved ~900 DST cycles retaining 80% capacity retention under 100% 4C rate (15 minute) fast-charge conditions
- DST cycling data was collected and validated by Idaho National Laboratory

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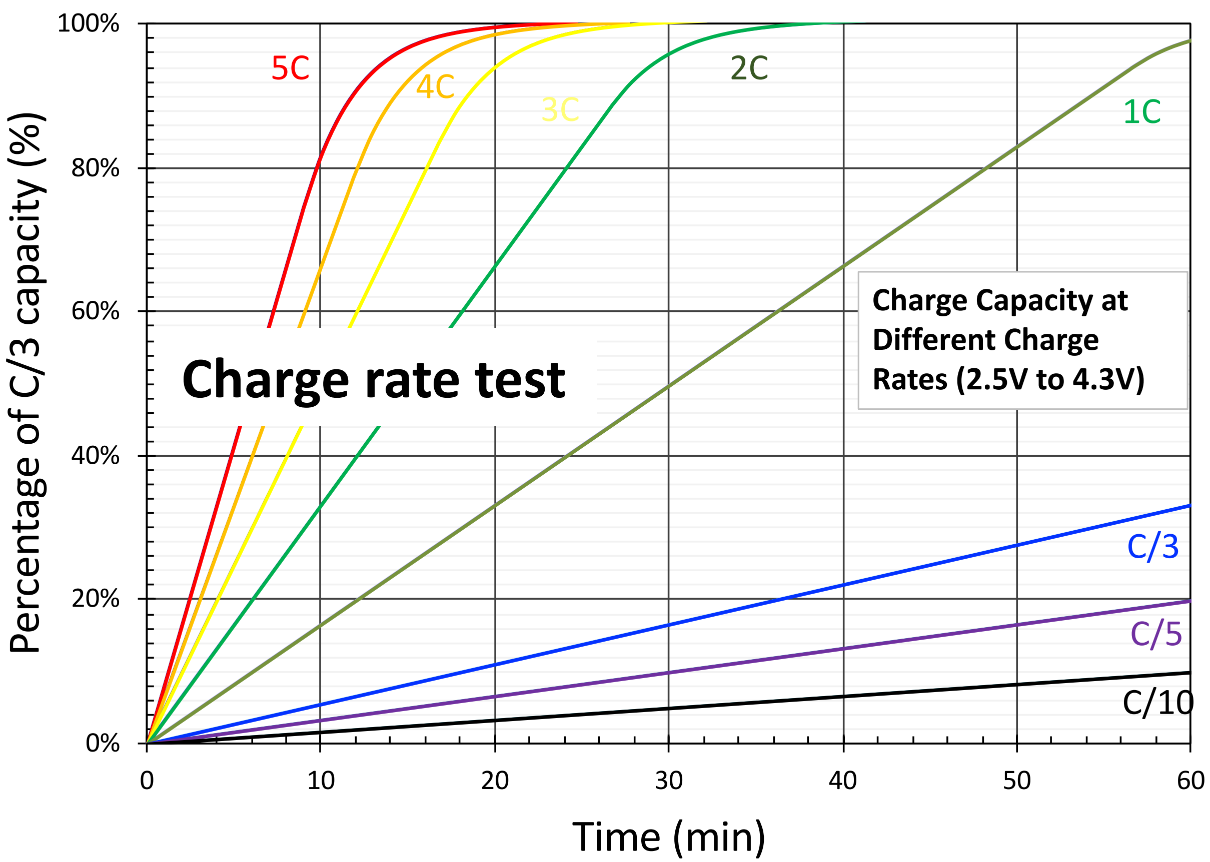
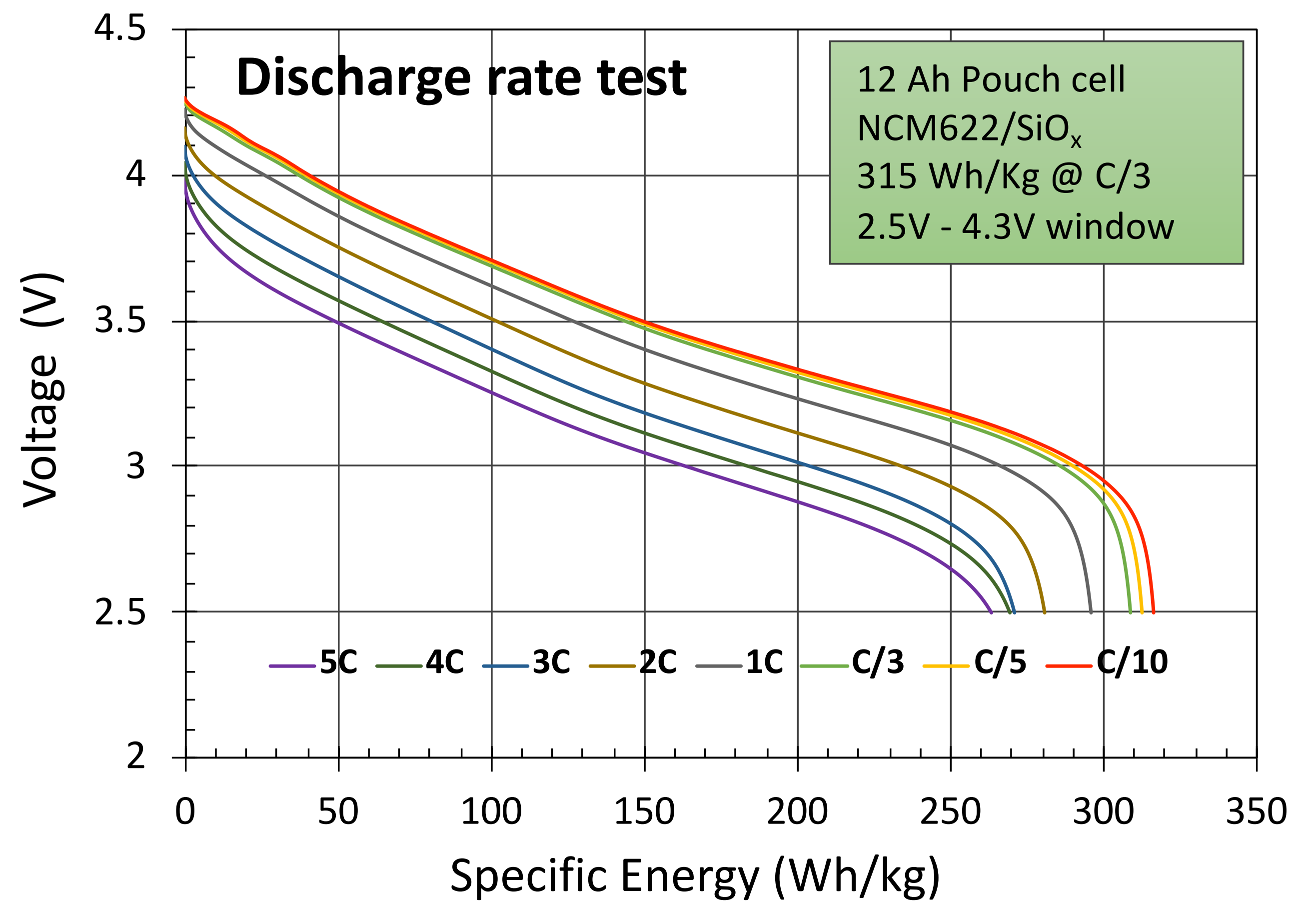
Charge & Discharge Rate Capability





- High energy silicon dominant cells show excellent charge and discharge rate capability
- Cells can be charged to 80% and 90% of their original C/3 capacity in 10 min and 15 min, respectively

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Gap Analysis of Cell Build #1

#	End of Life (EOL) Characteristics at 30°C	Units	USABC EOL Cell Level Targets	CB#1 - DST 0% FC		CB#1 - DST 100% FC		CB#1 - CL at 30˚C	
				BOL (RPT0)	EOL (RPT11)	BOL (RPT0)	EOL (RPT8)	BOL (RPT0)	EOL (RPT11)
1	Peak Discharge Power Density, 30 s Pulse	W/L	1400	3393*	2551*	3808*	1797*	3979*	1913*
2	Peak Specific Discharge Power, 30 s Pulse	W/kg	700	1380*	1037*	1548*	731*	1618*	778*
3	Peak Specific Regen Power, 10 s Pulse	W/kg	300	2605*	1731*	2225*	1708*	2598*	1883*
4	Available Energy Density @ C/3 Discharge Rate	Wh/L	550	742*	679*	825*	596*	846*	606*
5	Available Specific Energy @ C/3 Discharge Rate	Wh/kg	275	302*	276*	335*	242*	344*	246*
6	Available Energy @ C/3 Discharge Rate	kWh	50	>50	>50	>50	>50	>50	>50
7	Calendar Life	Years	10						0.96
8	DST Cycle life	Cycles	1000		1232		896		
9	Cost	$/kWh	75	169		169		169	
10	Normal Recharge Time	Hours	< 7 Hours, J1772	< 7hr		< 7hr		< 7hr	
11	Fast High Rate Charge	Minutes	80% ΔSOC in15 min	>80		>80		>80	
12	Minimum Operating Voltage	V	>0.55 Vmax	0.58 Vmax	0.58 Vmax	0.58 Vmax	0.58 Vmax	0.58 Vmax	0.58 Vmax
13	Unassisted Operating at Low Temperature	%	> 70% E_{usable} @ C/3 Discharge rate at -20°C	79		79		79	
14	Survival Temperature Range, 24 Hr	°C	-40 to + 66	TBD	TBD	TBD	TBD	TBD	TBD
15	Maximum Self-discharge	%/month	< 1	TBD	TBD	TBD	TBD	TBD	TBD
16	Battery scaling factor (BSF)	# of cells	288 (96s, 3p)	1536 (96s, 16p)	1536 (96s, 16p)	1536 (96s, 16p)	1536 (96s, 16p)	1536 (96s, 16p)	1536 (96s, 16p)
17	Battery capacity	Ah	>40	12	12	12	12	12	12

- Cell build #1 of the program meets the majority of the USABC low-cost/fast-charge advanced EV cell targets for 2023
- Final cell build of the program intends to improve the calendar life performance, reduce cell cost and increase energy
- * data collected by Idaho National Laboratory

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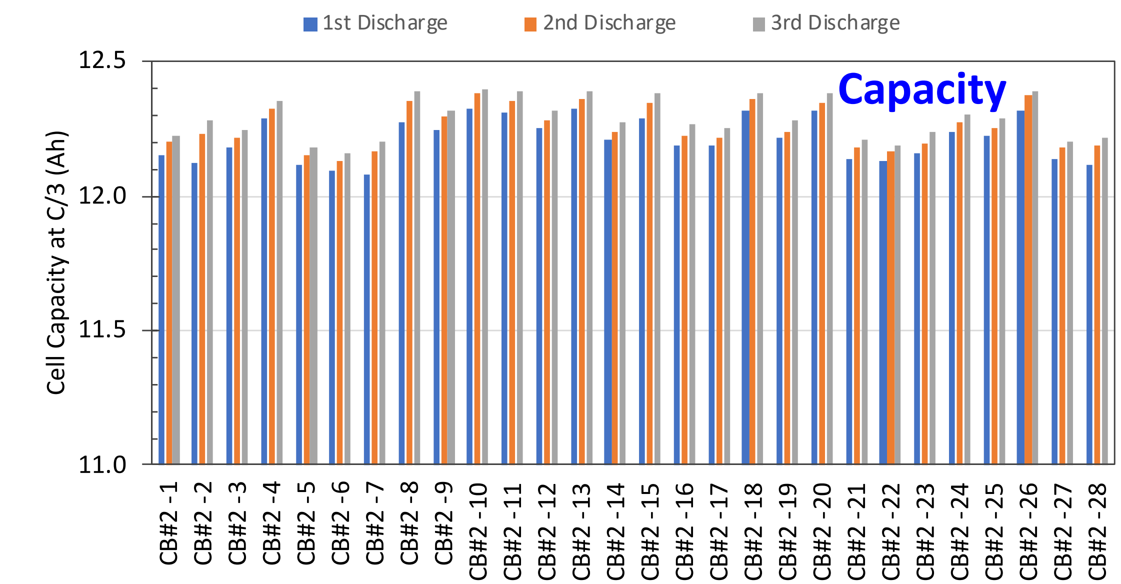
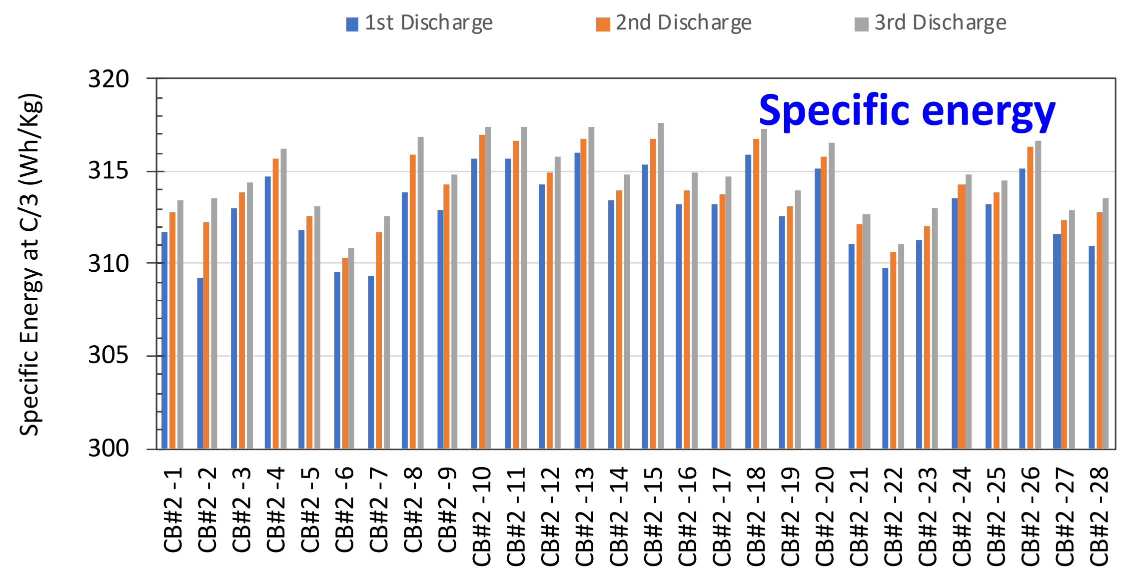
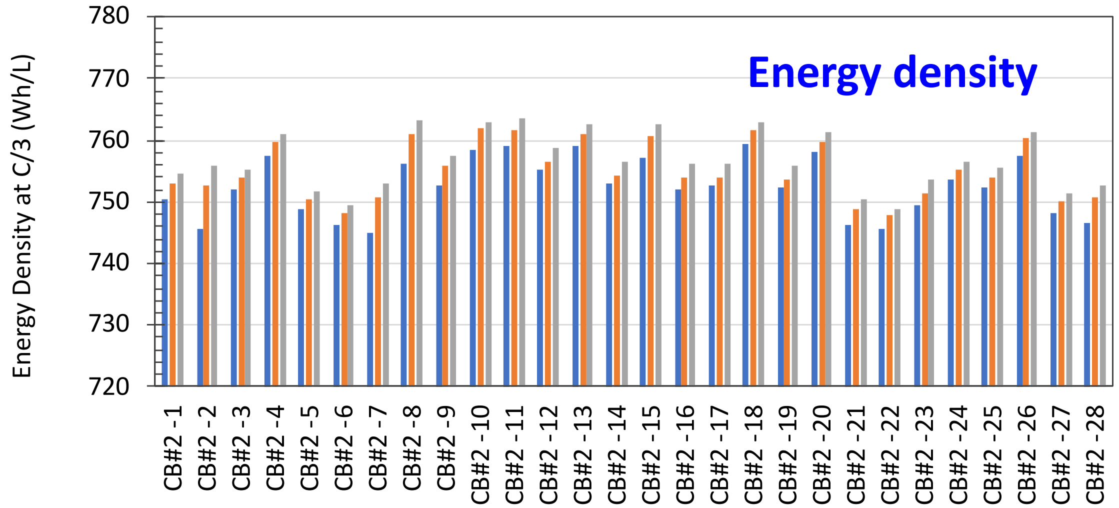
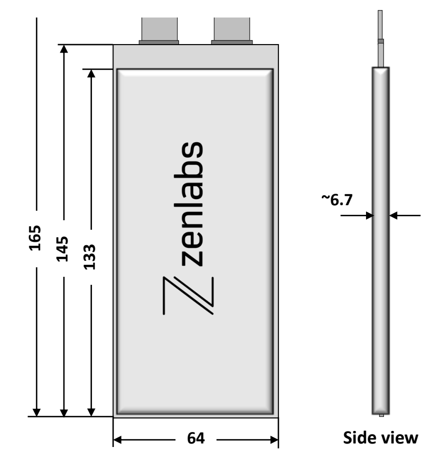
Cell Build #2 (CB#2) Deliverable







- 37 CB#2 pouch cell were delivered to the National Labs (INL, SNL, NREL) for independent testing
- Cells showed good reproducibility with an average C/3 rate **capacity of 12.3 +/- 0.1 Ah**, **specific energy of 315 +/- 2 Wh/Kg** and **energy density of 757 +/- 5 Wh/L** (without terrace)
- Testing is ongoing both at Zenlabs and the National Labs



Dimensions in mm (not to scale)

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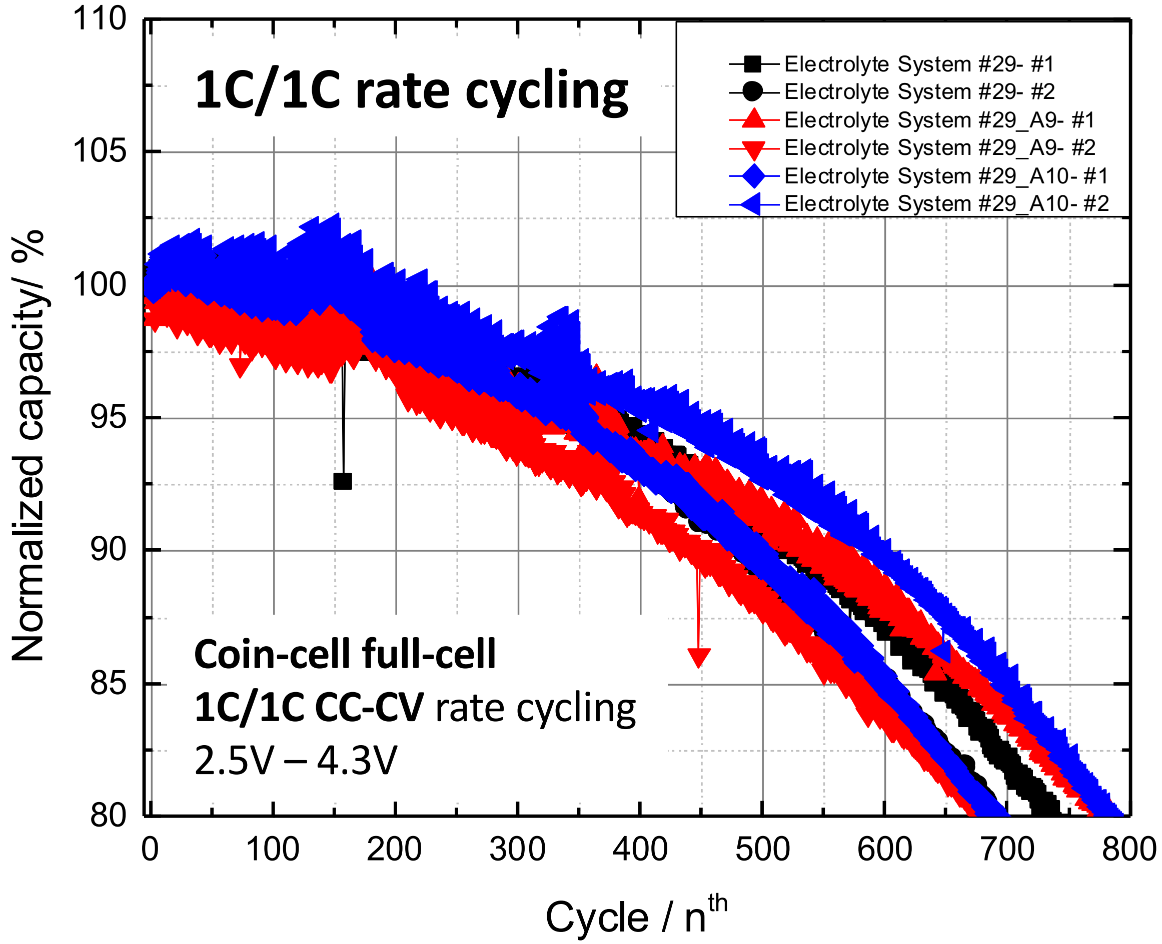
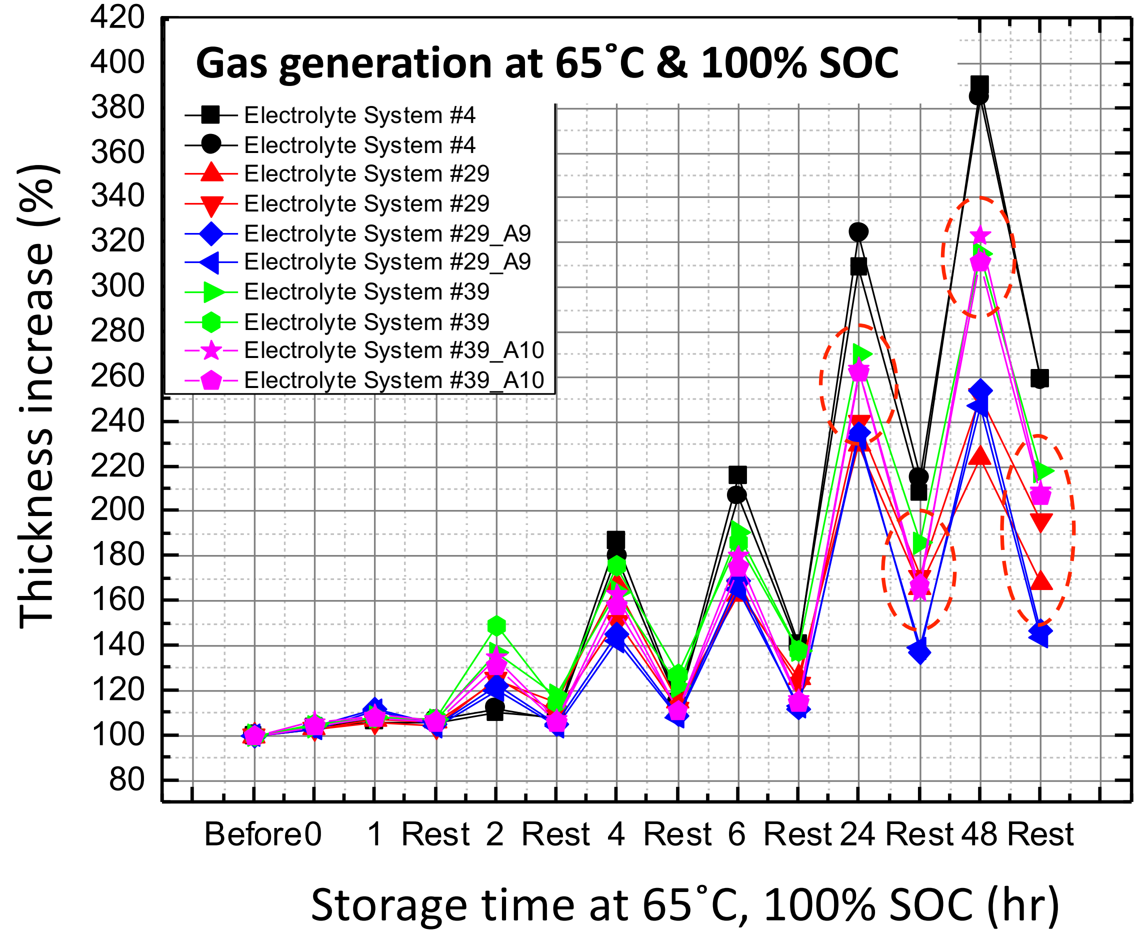
Electrolyte Development





- Electrolyte formulations have been optimized to reduce the gas generation during 65˚C and 10% SOC storage
- Electrolyte formulations have been optimized for standard 1C rate cycling and 4C rate (15 min) fast-charge cycling

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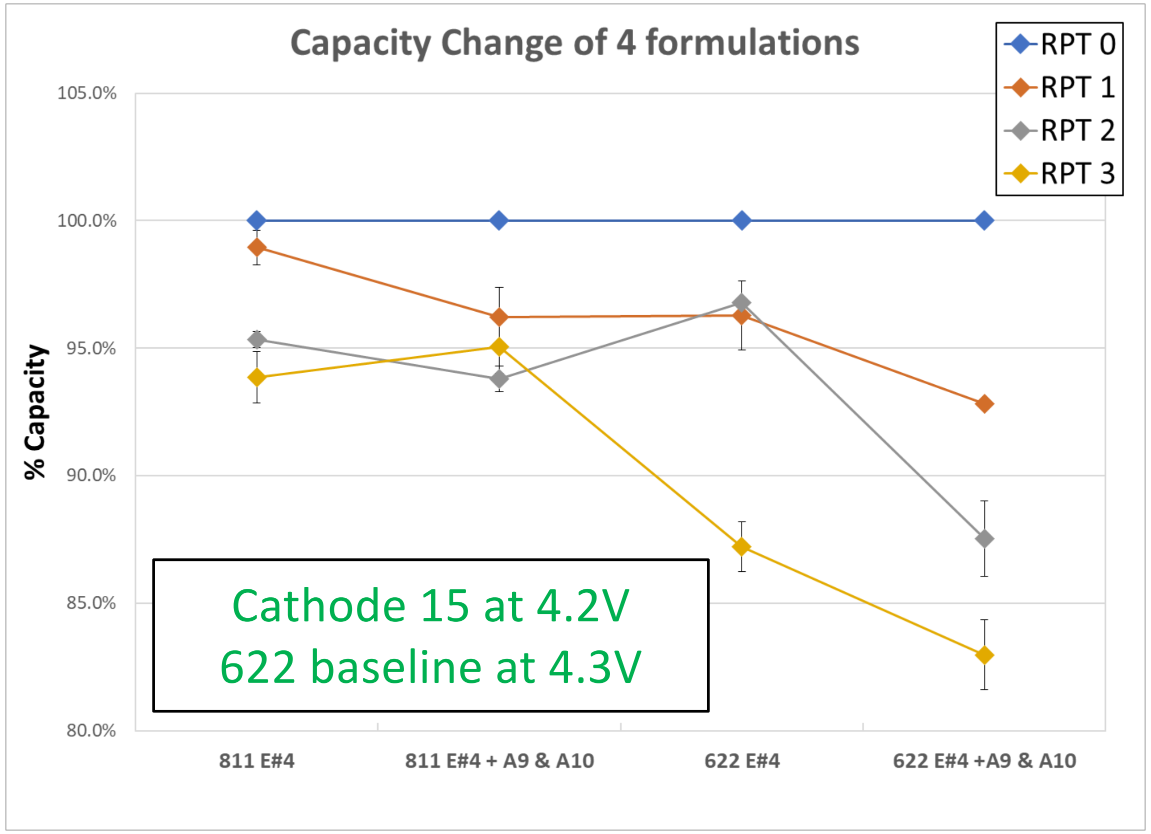
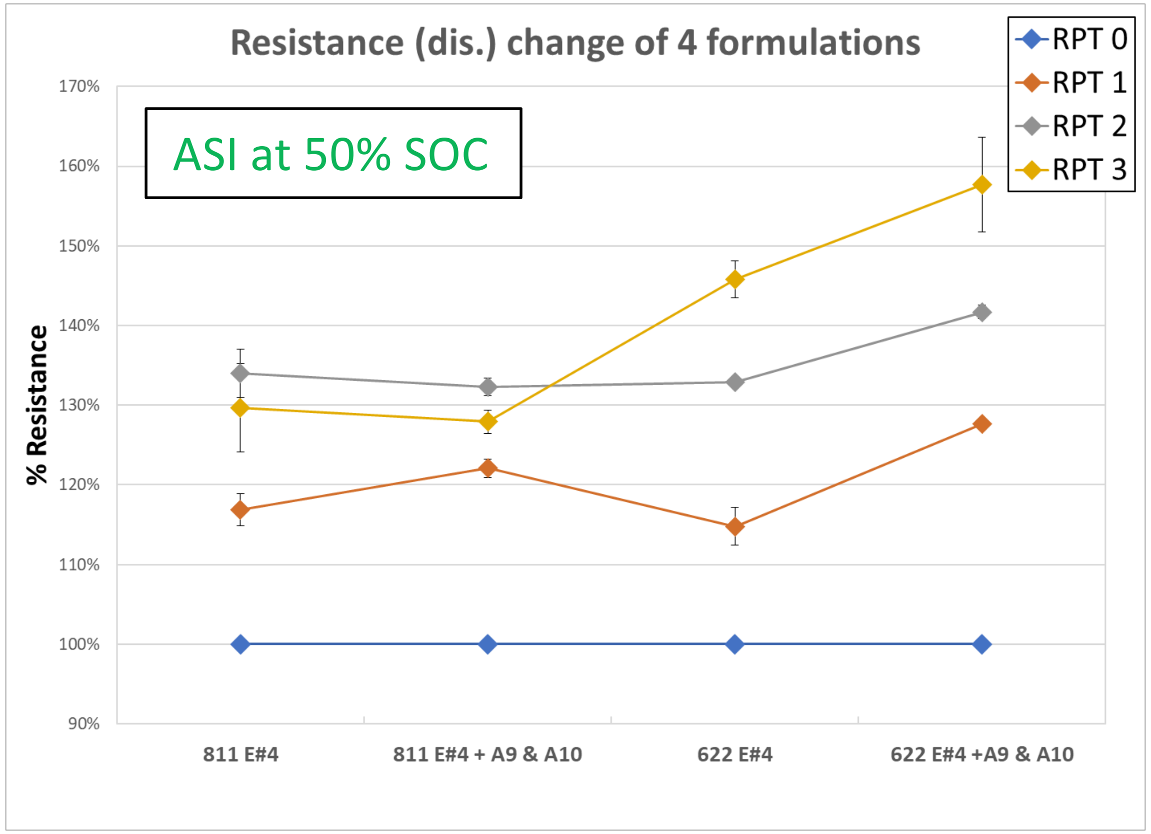
Fast-screening Calendar Life Protocol





- A fast-screening Calendar Life (CL) Protocol using coin-cells stored at 50˚C has been developed
- Results show that the cathode chemistry impacts the capacity fade & resistance growth, with NCM 811 showing improved CL behavior
- Integration of electrolyte additives (A9 & A10) are showing a negative impact to the CL performance

Responses to Reviewers Comments

What postmortem testing do you do on coin cell screening and/or pouch cells to understand the improvements that you are seeing with electrolyte and active material variations? Understanding the failure mechanisms is important as we work to improve and meet the cell targets. Typically, postmortem analysis is performed on pouch cells after cycling (CCCV or DST) or calendar life testing. During the postmortem evaluation, we try to understand if the cell failures are related to the silicon anode, NCM cathode, electrolyte, etc. by performing visual inspections, chemical and structural analysis, physical and mechanical testing and electrochemical evaluation of the active and inactive components.

What is the primary mechanism of capacity loss that you are still seeing with the CB#1 that you hope to address in CB#2? Currently CB#1 cells are exceeding 1000 cycles at C/3 rate DST cycling and showing nearly 900 DST cycles under 100% fast-charge (4C rate) conditions. One concern from CB#1 is cell gassing. One of the goals of CB#2 and CB#3 are to improve the electrolyte formulation to reduce cell gassing while maintaining the same or improved cycling and calendar life performance. Reducing the gassing will eliminate the risk of pre-maturely stopping the cycling or calendar life testing of the cells.

And what are your thoughts on what is limiting calendar life with SiO2-based anodes? Continual SEI growth that results in resistance increase and power reduction is one of the main areas we are addressing to improve calendar life.

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Collaborations

UNITED STATES ADVANCED BATTERY CONSORTIUM

- Stellantis, GM, Ford & DOE – Guidance and support on the technology development, cost model and cell specs & testing

Idaho National Laboratory

- INL – Cell testing including energy, power, cycle life, calendar life, rate and high and low temperature performance

Sandia National Laboratories

- SNL – Abuse testing including short circuit, overcharge, thermal ramp and nail penetration

NATIONAL RENEWABLE ENERGY LABORATORY

- NREL – Thermal performance characterization including heat generation, cell efficiency and thermal imaging

Remaining Challenges and Barriers

- Meeting the calendar life (CL) targets from high energy silicon-dominant cells continues to be a significant challenge. Especially since CL testing is time consuming and requires long periods of time to collect the data
- Optimization of the electrolyte formulation to reduce gassing and at the same time maintain the high-energy, high-power, fast-charge and long cycle life targets continue to be a challenge
- Down-selecting high performing and cost-effective active and passive cell components able to meet the USABC cell cost targets
- Developing a robust, manufacturable and cost-effective pre-lithiation solution
- Continue to improve the cell assembly reproducibility and automation of high capacity (> 50 Ah) large footprint (320 mm x 102 mm) pouch cells

Proposed Future Research

- Developed a fast-screening calendar life protocol to understand the mechanisms and identify and optimize the parameters that impact CL. Continuing to evaluate various electrolyte formulations, active materials & cell designs to improve CL.
- Down-selecting electrolyte formulation for final CB#3 to reduce gassing, improve CL and enhance safety while continuing to meet the USABC cell specs
- Down-select high-capacity Ni-rich NCM cathode, low cost SiOx active material, and a cost-effective pre-lithiation solution to meet the low-cost cell targets
- Continue to support equipment manufacturer to develop and optimize a robust, manufacturable and cost-effective pre-lithiation solution
- Upgrading cell prototyping facility to be able to reliably assemble high capacity (> 50 Ah) large footprint (320 mm x 102 mm) pouch cells

Summary

- **Have achieved >1000 cycles** to 80% capacity retention from 12 Ah, 315 Wh/kg pouch cells (rated at C/3) at 1C rate CC-CV cycling and C/3 charge rate DST cycling.
- **Have achieved ~900 DST cycles** to 80% capacity retention under 100% 4C rate (15 minute) fast-charge conditions.
- High energy silicon dominant cells show excellent charge and discharge rate capability with cells charging to **80% and 90% of their original C/3 capacity in 10 min and 15 min**, respectively.
- Have delivered CB#2 cells to the National Labs and testing is ongoing both at Zenlabs and the National Labs.
- Developed a fast-screening calendar life protocol to understand and optimize the parameters (electrolyte formulations, active materials & cell designs) that impact CL
- Optimized electrolyte formulations to reduce gas generation while maintaining energy, rate and cycle life of the cell.
- Continue to support different pre-lithiation approaches to enable a robust, manufacturable and cost-effective pre-lithiation solution for silicon-dominant anodes.